DOE Project ID: DE-SC0008561
Institution: Texas A&M University
Principal Investigator: Courtney Schumacher
Title: The 3-D Tropical Convective Cloud Spectrum in AMIE Radar Observations and Global Climate Simulations

Final project report for 1 September 2012 – 31 August 2015

During the three years of this grant performance, the PI and her research group have made a number of significant contributions towards determining properties of tropical deep convective clouds and how models depict and respond to the heating associated with tropical convective systems. The PI has also been an active ARM/ASR science team member, including playing a significant role in AMIE and GoAmazon2014/5. She served on the DOE ASR radar science steering committee and was a joint chair of the Mesoscale Convective Organization group under the Cloud Life Cycle working group. This grant has funded a number of graduate students, many of them women, and the PI and her group have presented their DOE-supported work at various universities and national meetings.

Observational studies

The PI and her group participated in the AMIE (2011-12) and GoAmazon2014/5 (2014-15) DOE field deployments that occurred in the tropical Indian Ocean and Brazilian Amazon, respectively. AMIE observational results (DePasquale et al. 2014, Feng et al. 2014, Ahmed and Schumacher 2015) focus on the variation and possible importance of Kelvin waves in various phases of the Madden-Julian Oscillation (MJO), on the synergy of the different wavelength radars deployed on Addu Atoll, and on the importance of humidity thresholds in the tropics on stratiform rain production. Much of the PIs GoAmazon2014/5 results to date relate to overviews of the observations made during the field campaign (Martin et al. 2015, 2016; Fuentes et al. 2016), but also include the introduction of the descending arm and its link to ozone transport from the mid-troposphere to the surface (Gerken et al. 2016). Vertical motion and mass flux profiles from GoAmazon (Giangrande et al. 2016) also show interesting patterns between seasons and provide targets for model simulations. Results from TWP-ICE (Schumacher et al. 2015), which took place in Darwin, Australia in 2006 show that vertical velocity retrievals from the profilers provide structure to better quantify the transition between convective, stratiform, and anvil cloud types.

DePasquale, A., **C. Schumacher**, and A. Rapp, 2014: Radar observations of MJO and Kelvin wave interactions during DYNAMO/CINDY2011/AMIE. *J. Geophys. Res. -Atmos.*, **119**, doi:10.1002/2013JD021031.

Feng, Z., S. A. McFarlane, **C. Schumacher**, S. Ellis, J. Comstock, and N. Bharadwaj, 2014: Constructing a merged cloud-precipitation radar dataset for tropical convective clouds during the DYNAMO/AMIE experiment at Addu Atoll. *J. Atmos. Ocean Tech.*, **31**, 1021-1042.

Ahmed, F., and **C. Schumacher**, 2015: Convective and stratiform components of the precipitation-moisture relationship. *Geophys. Res. Lett.*, **42**, 10,453–10,462, doi:10.1002/2015GL066957.

Schumacher, C., S. Stevenson, and C. Williams, 2015: Vertical motions of the tropical

convective cloud spectrum over Darwin, Australia. *Quart. J. Roy. Meteor. Soc.* DOI:10.1002/qj.2520.

Gerken, T., D. Wei, R. J. Chase, J. D. Fuentes, **C. Schumacher**, L. A. T. Machado, R. V. Andreoli, M. Chamecki, R. A. Ferreira de Souza, L. S. Freire, A. B. Jardine, A. O. Manzi, R. M. Nascimento dos Santos, C. von Randow, P. dos Santos Costa, P. C. Stoy, J. Tota, and A. M. Trowbridge, 2016: Downward transport of ozone rich air and implications for atmospheric chemistry in the Amazon rainforest. *Atmospheric Environment*, DOI:10.1016/j.atmosenv.2015.11.014.

Martin, S. T., P. Artaxo, L. A. T. Machado, A. O. Manzi, R. A. F. Souza, **C. Schumacher**, J. Wang, M. O. Andreae, H. M. J. Barbosa, J. Fan, G. Fisch, A. H. Goldstein, A. Guenther, J. L. Jimenez, U. Poschl, M. A. Silva Dias, J. N. Smith, and M. Wendisch, 2016: Introduction: Observations and modeling of the Green Ocean Amazon (GoAmazon2014/5). *Atmos. Chem. Phys.*, **16**, 4785-4797, doi: 10.519/acp-16-4785-2016.

Fuentes, J. D., M. Chamecki, R. M. Nascimento dos Santos, C. von Randow, P. Stoy, G. Katul, D. R. Fitzjarrald, A. O. Manzi, T. Gerken, A. Trowbridge, L. S. Freire, J. Ruiz-Plancarte, J. M. F. Maia, J. Tota, N. L Dias, G. Fisch, **C. Schumacher**, O. Acevedo, and J. R. Mercer, 2016: Linking meteorology, turbulence, and air chemistry in the Amazon rainforest during the GoAmazon project. *Bull. Amer. Meteor. Soc.*, in press.

Martin, S., P. Artaxo, L. Machado, A. Manzi, R. Souza, **C. Schumacher**, J. Wang, J. Brito, K. Jardine, A. Medeiros, S. de Sa, T. Biscaro, A. Calheiros, B. Portela, and 44 other authors in alphabetical order, 2016: The Green Ocean Amazon Experiment (GoAmazon2014/5) observes pollution affecting gases, aerosols, clouds, and rainfall over the rain forest. *Bull. Amer. Meteor. Soc.*, conditionally accepted.

Giangrande, S. E., T. Toto, M. P. Jensen, M. J. Barholomew, Z. Feng, A. Protat, C. R. Williams, **C. Schumacher**, and L. Machado, 2016: Convective cloud vertical velocity and mass-flux characteristics from radar wind profiler observations during GoAmazon2014/5. *J. Geophys. Res*, conditionally accepted.

Modeling studies

The PI and her research group have used tropics-wide heating profiles derived from satellite data (with guidance from ARM observations in the tropical West Pacific) to force GCMs to see the large-scale response to deep convection and upper level cloud (Li et al. 2013, Lappen and Schumacher 2014, Straus et al. 2015). Of particular note is a new method we developed to add heating to CAM4 while maintaining the model's fully interactive physics. The modeling results unequivocally show that an accurate horizontal *and* vertical distribution of heating are critical in the simulation of the MJO. This more accurate heating came from either satellite-derived latent heating or idealized heating that had a longitudinal tilt more like the observed MJO. Radiative heating of upper level cloud, on the other hand, only slightly modifies an idealized GCM (i.e., one without interactive physics) forced by observed latent heating suggesting that the impact of clouds is more important to large-scale tropical circulation variations because of convective feedbacks rather than direct cloud radiative forcing. Most recently, one of the PI's graduate students spent a summer at PNNL to create a latent heating retrieval (Ahmed et al. 2016) based on high-resolution regional model output from AMIE that can be applied to ground and space-borne radar observations and that is not dependent on surface rainfall amount, but rather focuses on the size and other mesoscale characteristics of the precipitating convective systems. A

recently submitted paper (Tang et al. 2016) describes results from the variational analysis during the two IOPs of GoAmazon2014/5 with emphasis on diurnal variations and differences in atmospheric budget parameters between the wet and transition seasons.

Li, W., C. **Schumacher**, and S. A. McFarlane, 2013: Radiative heating of the ISCCP upper level cloud regimes and its impacts on the large-scale tropical circulation. *J. Geophys. Res. -Atmos.*, **118**, doi:10.1002/jgrd.50114.

Lappen, C., and **C. Schumacher**, 2014: The role of tilted heating in the evolution of the MJO. *J. Geophys. Res. -Atmos.*, **119**, doi:10.1002/2013JD020638.

Straus, D. M., E. Swenson, and C. Lappen, 2015: The MJO cycle forcing of the North Atlantic circulation: Intervention experiments with the Community Earth System Model. *J. Atmos. Sci.*, **72**, 660-681.

Ahmed, F., **C. Schumacher**, Z. Feng, and S. Hagos, 2016: A retrieval of tropical heating using the 3D structure of precipitation features. *J. Appl. Meteor. Clim.*, doi:10.1175/JAMC-D-15-0038.1, in press.

Tang, S., S. Xie, Y. Zhang, M. Zhang, **C. Schumacher**, H. Upton, M. Jensen, K. Johnson, M. Wang, M. Ahlgrimm, Z. Feng, P. Minnis, and M. Thieman, 2016: Large-Scale vertical velocity, diabatic heating and drying profiles associated with seasonal and diurnal variations of convective systems observed in the GoAmazon2014/5 experiment. *Atmos. Chem. Phys*, submitted.